

BREAKDOWN SUPPRESSION IN ACCELERATING STRUCTURES USING ELECTRON BEAM PROCESSING

Vadim Jabotinski and Dr. Frederick Mako

**FM Technologies, Inc.
4431-H Brookfield Corporate Dr.
Chantilly, VA
Tel. : 703-818-9400 ext. 0
Fax: 703-818-7090**

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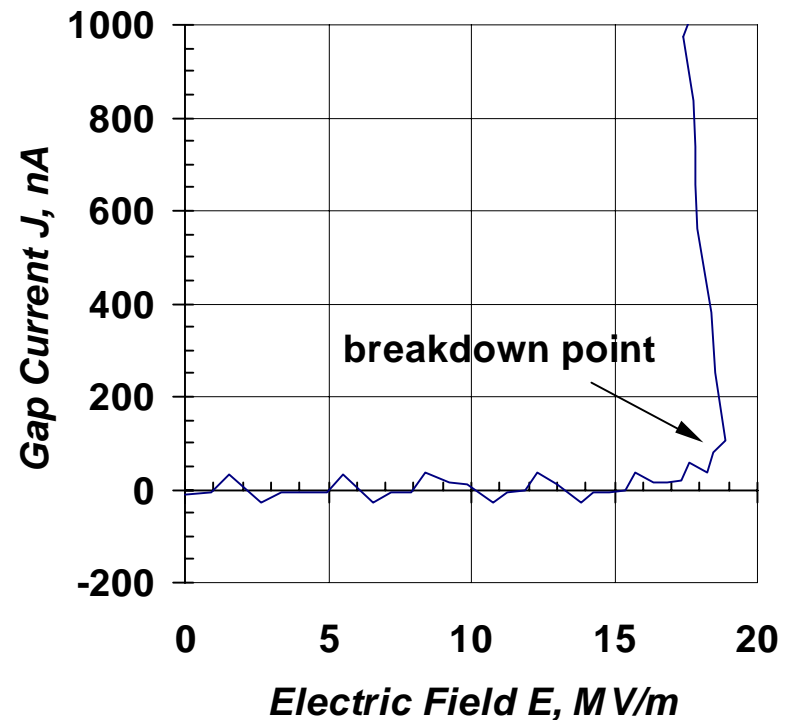
BREAKDOWN CAUSED ISSUES

Vacuum breakdown and high dark current occurring on copper and other electrode materials originate limits to the performance of RF cavities :

- **LIMITED ACCELERATION**
field gradient allowable
- **OVERHEATING OF ACCELERATING STRUCTURES** e.g. copper rings
mechanical stress, deformation, cracking
- **BACKGROUND RADIATION**
- **NOISE, INSTABILITY, PARAMETER SHIFT**

A technique to modify the surface properties of electrode materials to increase the breakdown threshold is needed.

WE HAVE ACHIEVED THE BREAKDOWN SUPPRESSION USING PULSED ELECTRON BEAM SURFACE MODIFICATION.



Vacuum Breakdown of OFE Cu measured with the diagnostic system.

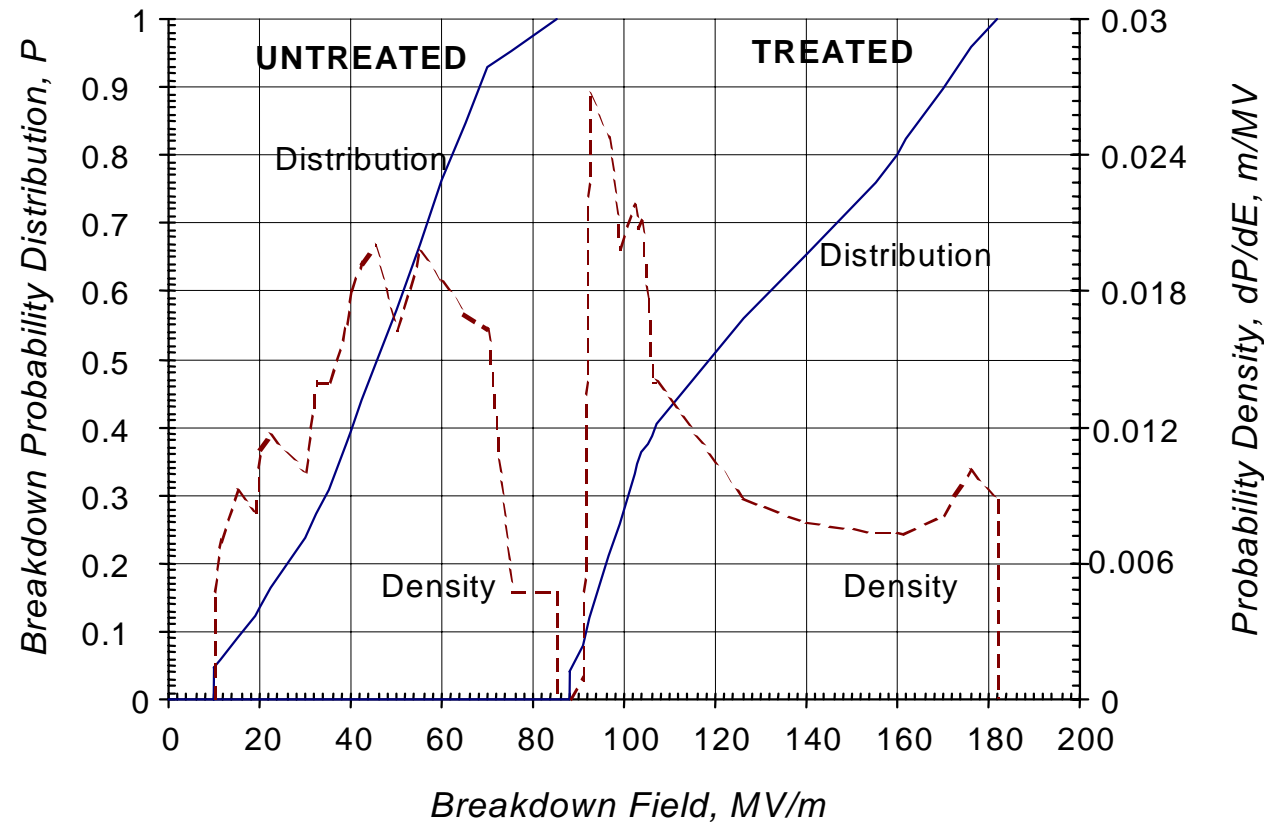
VACUUM BREAKDOWN DIAGNOSTICS DATA FOR OXYGEN FREE ELECTRONIC COPPER SHOWING EFFECT OF E-BEAM TREATMENT ON BREAKDOWN SUPPRESSION.

**Breakdown Threshold
Achieved (DC Test)**
90-180 MV/m

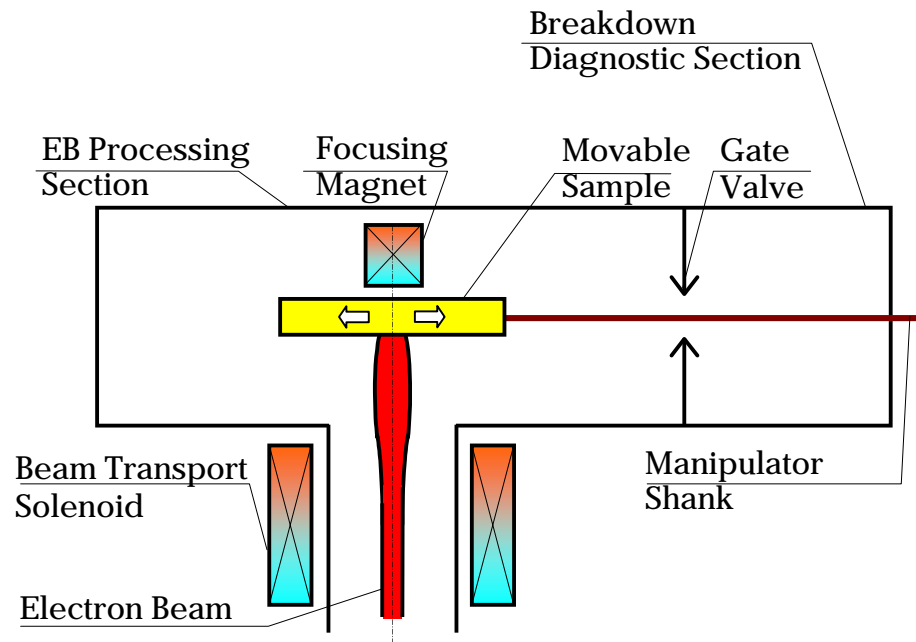
Vacuum
 $1-3 \cdot 10^{-8}$ Torr

Beam Print Size
Ø 10-30 mm

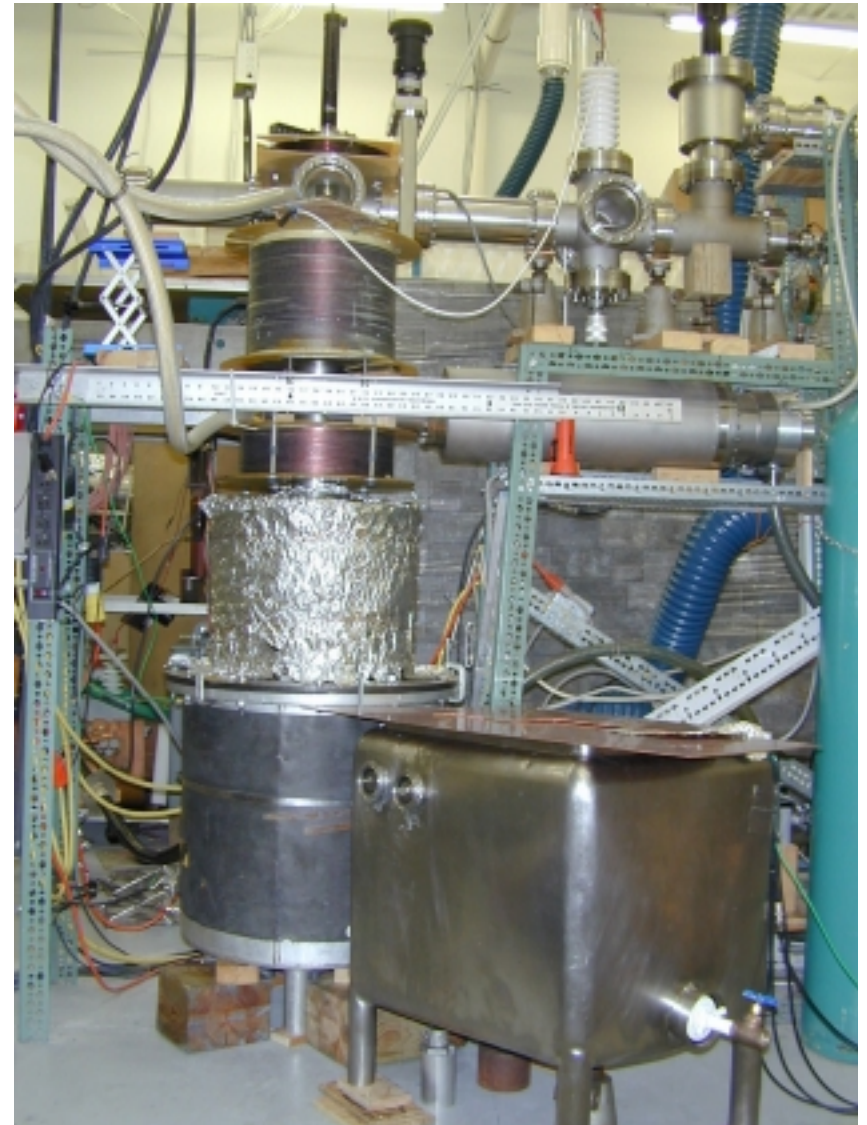
Sample Size
40x300 mm Cu plate



EXPERIMENTAL ELECTRON BEAM PROCESSING SYSTEM

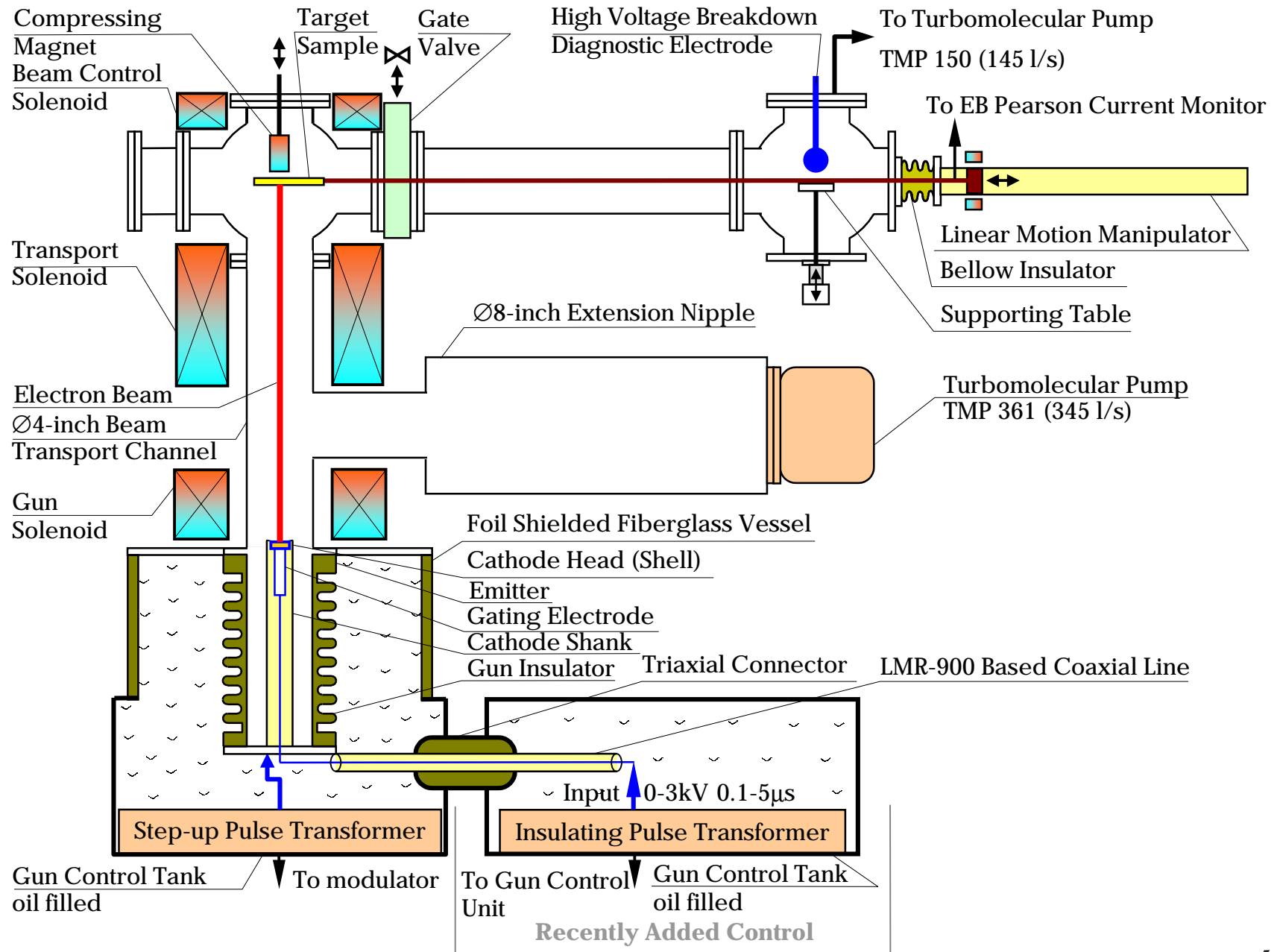


Schematic of Electron Beam Treatment Process.



Central Part of Electron Beam Treatment System.

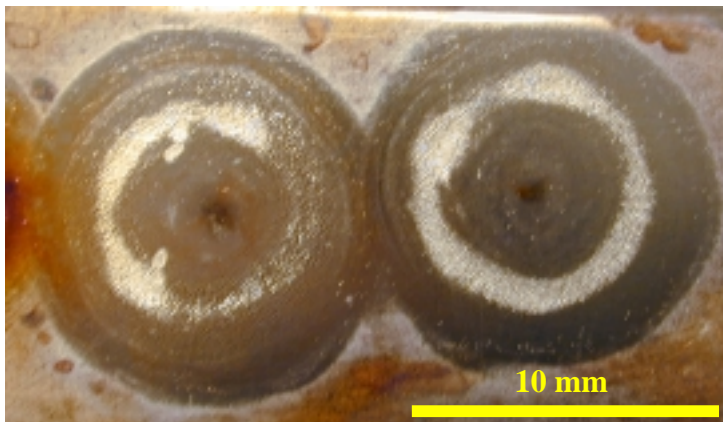
SCHEMATIC DIAGRAM OF ELECTRON BEAM PROCESSING SYSTEM



IRRADIATED SAMPLES OF OXYGEN FREE ELECTRONIC COPPER

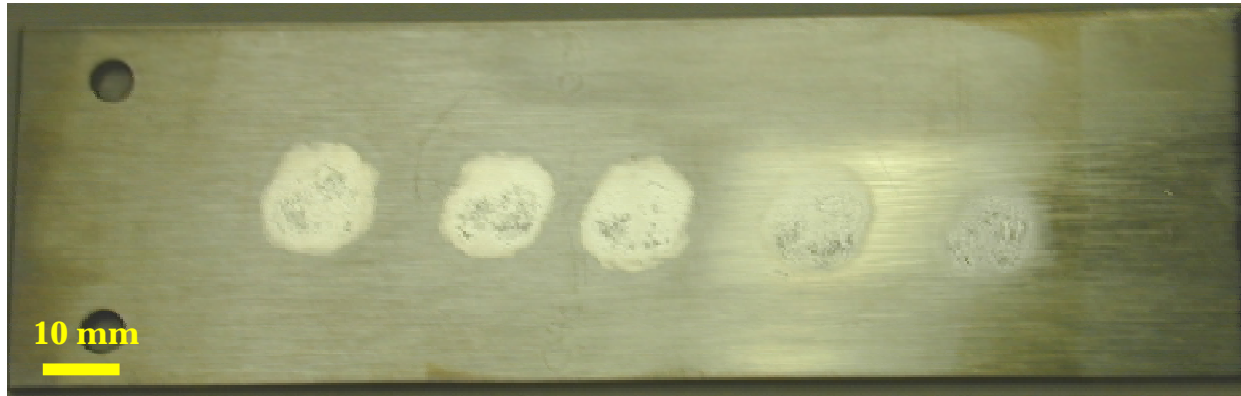


Beam Prints on Copper Plate Processed under Different Conditions of Electron Irradiation.

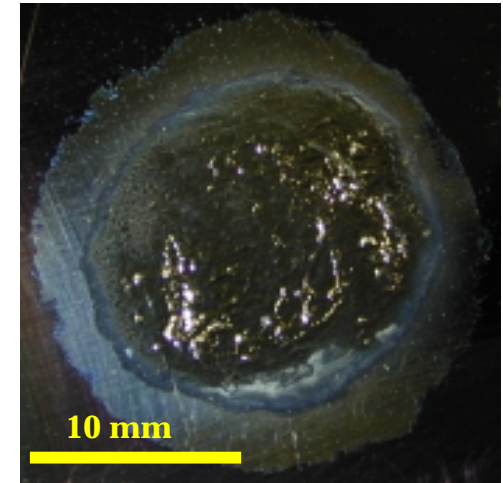


Overlapping Beam Prints on Copper Plate Exhibit Continuous Uniform Improved Breakdown Properties.

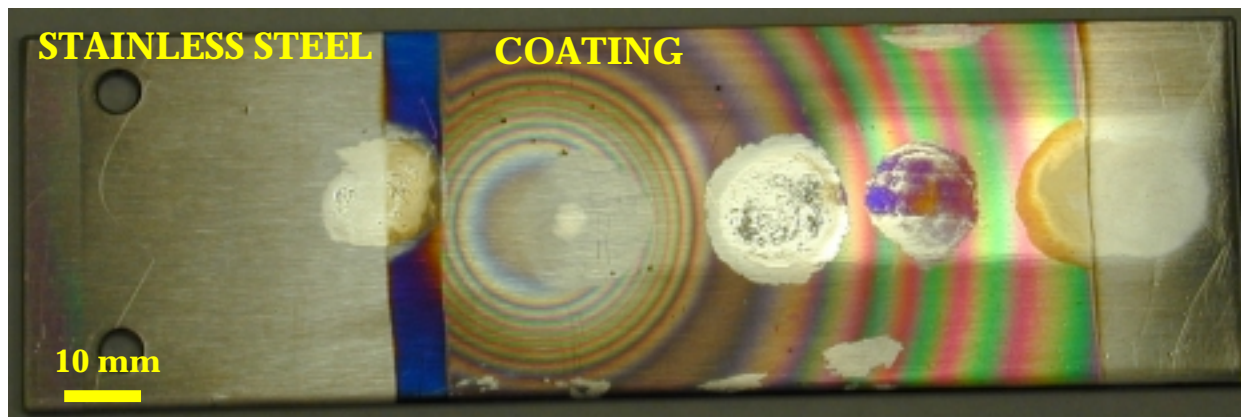
IRRADIATED SAMPLES OF STAINLESS STEEL 316L



Separate Processed Areas of Stainless Steel Plate.



Magnified View of Beam Print.



Beam Prints on Stainless Steel Plate Coated with Titanium Nitride Film.
The untreated coating breakdown threshold is 40 MV/m.
The breakdown threshold after electron beam processing is 110 MV/m.

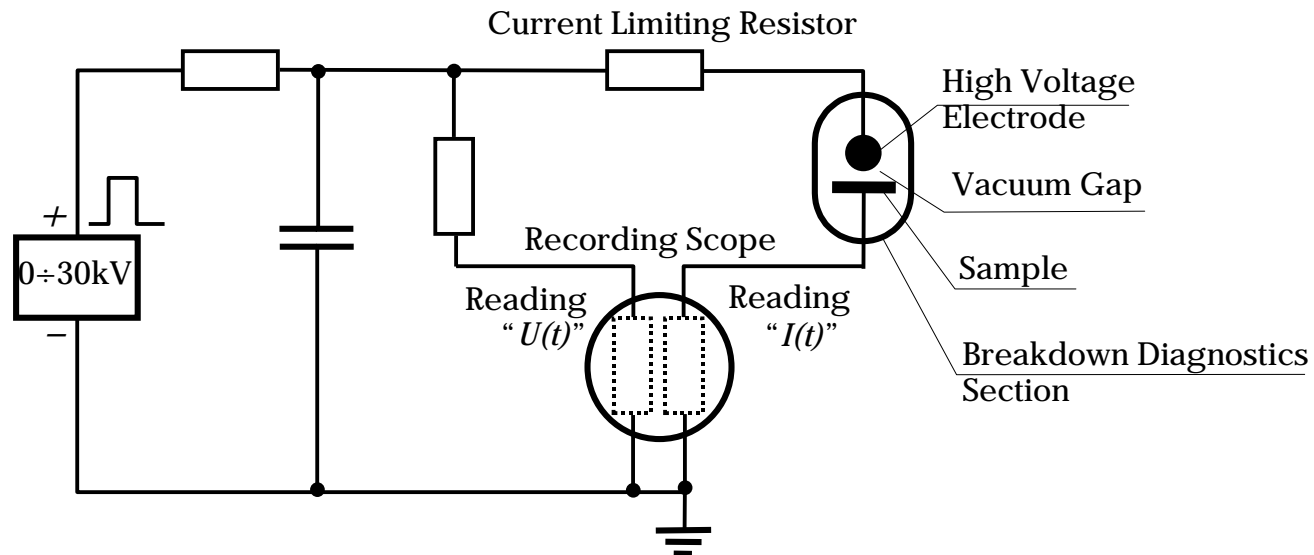
BREAKDOWN CHARACTERIZATION

Due to stochastic nature of breakdown the distribution of the probability of breakdown is measured.

- AVERAGE BREAKDOWN FIELD \rightarrow DARK CURRENT
- MINIMUM BREAKDOWN FIELD \rightarrow BREAKDOWN THRESHOLD

CONCEPTUAL SCHEMATIC OF BREAKDOWN MEASUREMENT

- REPRODUCIBILITY AND NEAR ZERO DESTRUCTION



SOURCES OF BREAKDOWN

1. PROTRUSIONS AND INTRUSIONS

- **Shape Effects.** Original and Foreign particles.
- **Properties Alteration** by surface contaminants e.g. CuO, or foreign particles, gaseous inclusions and voids.
 - Base material itself, e.g. copper
 - Work function; Conductivity; Dielectric constant
 - Structure: crystal orientation; intercrystalline and intergrain boundaries.

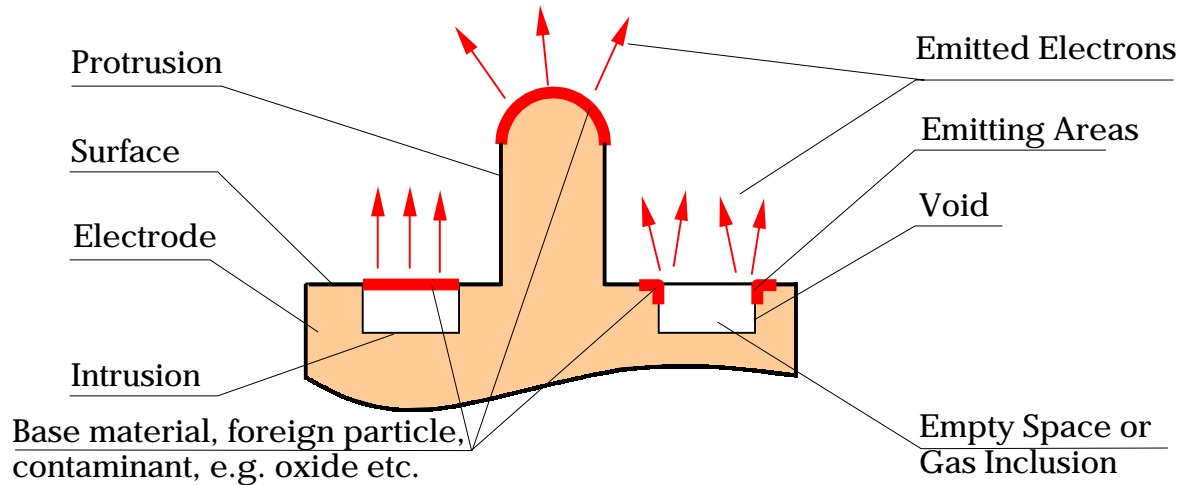


Illustration of Emission Sites.

2. VARIATION IN THE ADJACENT AREAS PROPERTIES

- Different work function → non-zero surface electric field → electron emission.

3. INTERACTION BETWEEN PLASMA AND EMITTING SURFACE

- strong electric field may be induced in the plasma – emitting surface gap causing the surface structural changes and consequently effecting on the emission process.

4. ANODE EFFECTS

- anode surface imperfections e.g. protrusions → high local leakage current densities → overheating and producing plasma → further leakage current increase and breakdown
- bombardment by accelerated charged particles from cathode → producing more anode surface defects → flying back secondary particles to hit cathode can trigger breakdown

UNIQUE ADVANTAGES OF ELECTRON BEAM

- **HIGH PULSE POWER**

Fast deposition of high amount of energy into material is not a limiting factor and achieved with feasible technical efforts

- **SOURCE OF CONCENTRATED ENERGY**

Electron beam concentrated in $\varnothing 5\div 50$ mm area is optimal for many applications. It allows

- precision control
- high density of the deposited energy
- rapid cooling and
- suppression of the thermal stress buildup.

- **BEAM PENETRATION AND RADIATION EFFECT**

When irradiating material, electron beam produces

- electron bombardment
- Bremsstrahlung, and
- volumetric source of heating.

These effects are unique to beam electrons, and are important for effective removal of gases absorbed in the material surface layer, smoothing and treating other surface imperfections.

CONCLUSION

ELECTRON BEAM PROCESSING ALLOWS

- **Increase in breakdown threshold** of copper, stainless steel, and other structural electrode materials.
 - Breakdown suppression for copper plate samples at the level of **90-180 MV/m** in DC voltage test under the vacuum of 10^{-8} Torr.
 - **Good reproducibility** across the beam prints on sample surface and between different samples.
 - Similar Improvement for **other than copper materials and coatings**.
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- WE ARE LOOKING FOR APPLICATION OF THE PROCESS IN HIGH GRADIENT ACCELERATING STRUCTURES
 - LARGE AREA AND LARGE DIAMETER 200 MHZ CAVITIES FOR MUON ACCELERATORS ARE OF INTEREST